Autonomous Disturbance Detection and Monitoring System with UAVSAR

Yunling Lou, Steve Chien, Ron Muellerschoen, and Sassan Saatchi
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive, MS 300-243
Pasadena, California 91109

Abstract - **We are developing an autonomous disturbance detection and monitoring system with imaging radar that combines the unique capabilities of imaging radar with high throughput onboard processing technology and onboard automated response capability based on specific science algorithms. This smart sensor development leverages off recently developed technologies in real-time onboard synthetic aperture radar (SAR) processor and onboard automated response software as well as science algorithms previously developed for radar remote sensing applications. In this project, we will modify the high rate data interface to ingest UAVSAR data and modify the onboard SAR processor software by adding motion compensation and antenna beam steering capabilities. We will also improve the fidelity of the onboard SAR processor by implementing polarimetric calibration capabilities and science algorithms for detecting and monitoring fire and hurricane-induced disturbances over the US forests. We will develop artificial intelligence for decision-making, and adapt existing onboard activity replanning and execution software to interface with UAVSAR. The product of this development is a prototype smart sensor for demonstration on NASA's UAVSAR, a compact, L-band polarimetric repeat-pass InSAR, which will begin engineering flights in 2007 and science data collection in 2008. We will use UAVSAR to demonstrate a closed loop smart sensor.**

I. INTRODUCTION

The unique capabilities of imaging radar to penetrate cloud cover and collect data in darkness over large areas at high resolution makes it a key information provider for the management and mitigation of natural and human-induced disasters such as earthquakes, volcanoes, landslides, floods, and wildfires. These capabilities are also vital in the exploration of planetary bodies such as Titan, Europa, and Venus. The challenges are its high raw data rate, requiring large onboard data storage and high downlink capability, and low data latency, requiring delivery of perishable information in time to be of use. Recent onboard synthetic aperture radar (SAR) processor development [1] is the first step towards reducing the downlink data rate. High fidelity polarimetric and interferometric SAR (InSAR) processing technology will reduce the downlink data rate by hundreds of orders of magnitude. Onboard decision making and automated response capabilities will enable us to vary the data collection rate and retarget data acquisition on the fly.

An autonomous system that combines the advantage of radar's all weather capability to penetrate through clouds and collect data at night with high fidelity, high throughput onboard processing technology and application-specific onboard automated response capability will directly address one of NASA's major objectives: to "develop new capabilities to advance Earth observation from space and reduce the risk, cost, size, and development time of future Earth Science space-based and ground-based operational systems." In particular, the onboard processing capability will contribute to several radar-based mission concepts for monitoring natural hazards and the global carbon cycle. Forest fire and hurricane-induced damages on coastal landscapes and forests are considered the two most important disturbances of natural ecosystems and threats to human habitats. These disturbances also impact the national and global carbon stocks and sequestration capacity by removing the forest biomass and in turn changing the dynamics of the global carbon cycle.

In this paper, we will describe our plan to adapt the change detection on-board processor (CDOP) previously developed in the AIST-02 project to process UAVSAR data. We will utilize onboard automated response experience from Autonomous Sciencecraft Experiment (ASE) onboard the New Millennium Earth Observation One spacecraft (EO-1) to implement automated disturbance detection and monitoring capability for forest fire and hurricane-induced damages applications. We plan to demonstrate this prototype smart sensor with NASA's UAVSAR, an L-band polarimetric repeat-pass interferometric SAR system. We will use UAVSAR to demonstrate automated response based on its own prior observation.

II. FOREST FIRE SENSOR WEB CONCEPT

Figure 1 shows the detection and response architecture of a forest fire sensor web. Major ecosystems of the world (boreal and tropical forests, shrub-lands, grasslands, and savannas) experience recurrent fires as a result of natural causes or human activities. Understanding fire behavior characteristics and planning for fire management require maps showing the distribution of wildfire fuel loads at medium to fine spatial resolution across large landscapes. In most wildfire simulation models such as FARSITE [2], variables such as the canopy height, biomass, and moisture content are important input data layers. Radar sensors from airborne or spaceborne platforms have the potential of providing real-time quantitative information about the forest structure and biomass components that can be readily translated to meaningful fuel loads for fire management [3]. Radar interferometric measurements of forest canopy height and the polarimetric data for estimating the canopy biomass and moisture are two important elements that will be explored in the forest fire scenario for intelligent onboard processing [4]. By integrating calibrated and tested algorithms, the processor will provide high spatial resolution maps and quantitative information for rapid response forest fire applications.

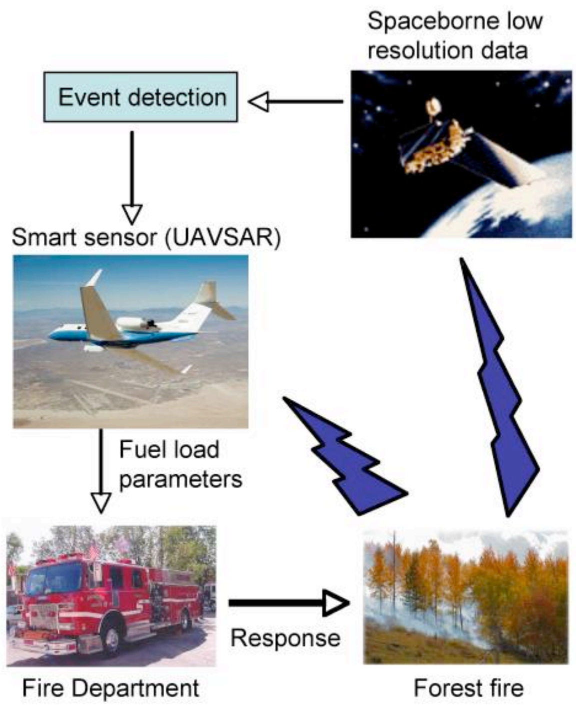

Figure 1. The detection and response architecture of a forest fire sensor web. Based on fire detection from a spaceborne observation, the smart sensor will plan new data acquisition, acquire high resolution radar data, perform onboard processing, and downlink high spatial resolution maps and fuel load parameters to the Fire Department for real-time fire management.

III. UAVSAR SMART SENSOR DESIGN

Figure 2 shows the operational scenario of the UAVSAR-based smart sensor. Raw data from the radar observation are routed to the onboard processor via a high-speed serial interface. The onboard processor will perform SAR image formation in real time on two raw data streams, which could be data of two different polarization combinations or data from two different interferometric channels. The onboard processor will generate real-time high resolution imagery for both channels. The onboard processor will also execute calibration routines and science algorithms appropriate for the specific radar application. Autonomous detection is performed by an intelligent software routine designed to detect specific disturbances based on the results of science processing. If no change is detected, the process stops and the results are logged. If "change" due to specific disturbances is detected, the onboard automated response software will plan new observations to continue monitoring the progression of the disturbance. The new observation plan is routed to the spacecraft or aircraft computer to retarget the platform for new radar observations.

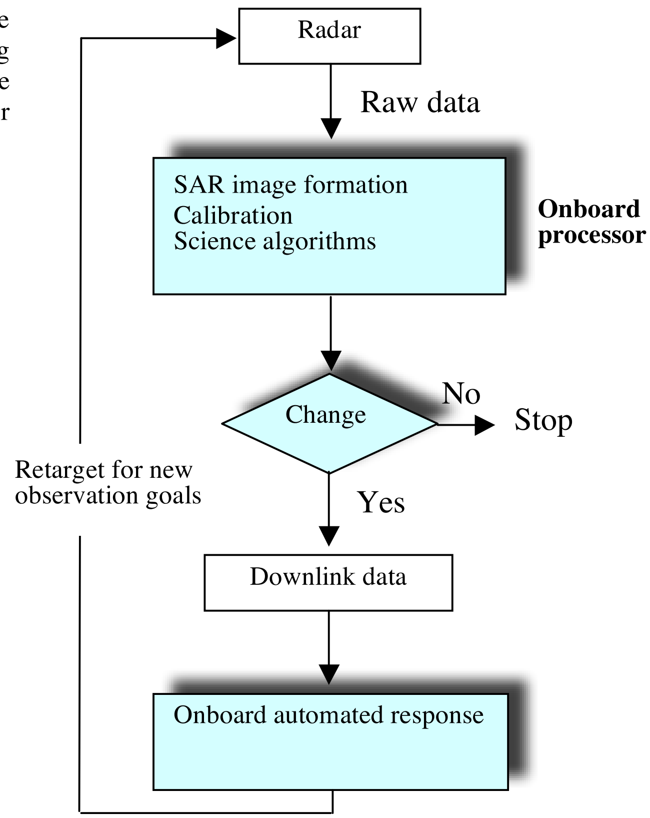

Figure 2. Operational scenario of the UAVSAR-based smart sensor.

The hardware for the prototype autonomous system is a self-contained VME chassis with single board computers and FPGA processor boards, high-speed serial interfaces for data routing, and Ethernet connection for processor control. Figure 3 shows the hardware architecture of the smart sensor. The VME-based change detection on-board processor (CDOP) consists of two custom FPGA boards with two Xilinx Virtex II-Pro FPGAs each and large high-speed Static Random Access Memory (SRAM) to perform real-time SAR image formation, a custom fibre-channel-to-RocketIO interface card to handle data transfer rate in excess of 1Gbps between the UAVSAR, processor components, and onboard memory. Two identical FPGA boards are utilized in order to perform SAR image formation of two raw data channels concurrently. Commercial off-the-shelf G4 PowerPC cards are used for preprocessing and polarimetric or interferometric post-processing. The processor control software consists of real-time, multi-threaded code that is running on the G4 CPU to route data from UAVSAR's data acquisition controller to the two FPGA processors and to generate processor parameters for two processor channels respectively.

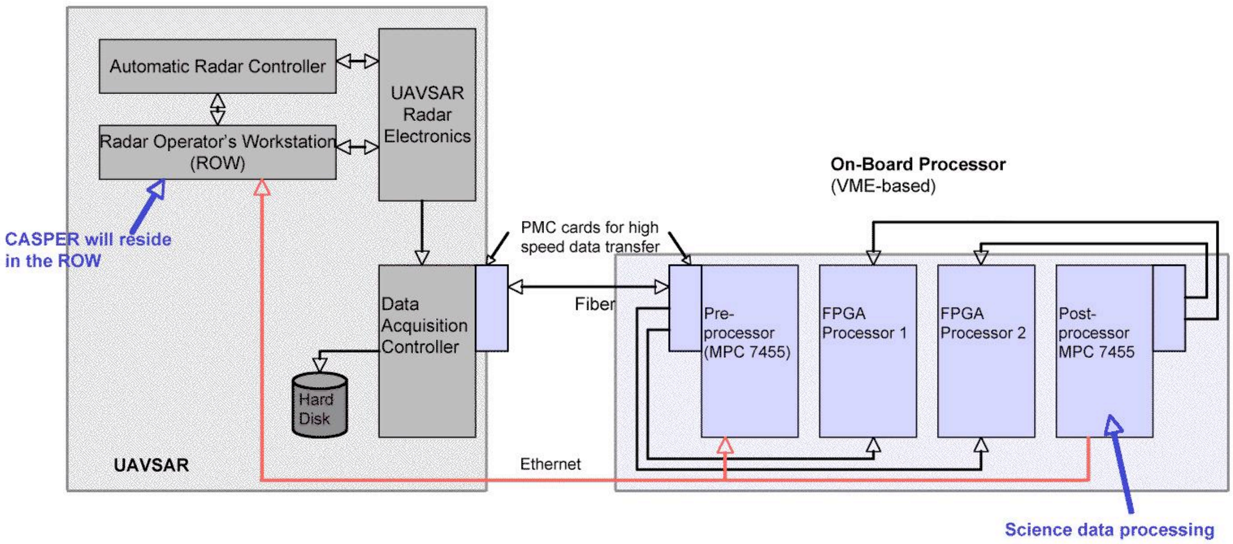

Figure 3. High level hardware architecture of the UAVSAR smart sensor.

The G4 PowerPC post-processor will perform the science data processing task, whereas autonomous detection and monitoring capability, as well as the Continuous Activity Scheduling Planning Execution and Replanning (CASPER) software, will reside either on UAVSAR's Radar Operator's Workstation (ROW) or a separate laptop computer.

We have inherited much of the CDOP hardware from the AIST-02 task and are building new data interfaces to the UAVSAR. This technology development will focus on the software development, algorithm adaptation, and validation of the intelligent onboard processor, adaptation of CASPER for our application, and interfaces to the UAVSAR for the smart sensor demonstration. We envision the successful demonstration will reduce the risk, cost, and development time for infusing the smart sensor technology into future spaceborne Earth observing missions.

IV. Onboard Processor Development

The UAVSAR onboard processor flow is shown in Figure 4. Live and/or archived raw data are first unpacked and reformatted before being routed to the FPGA processor. The pre-processor generates the phase correction factors for motion compensation and processing parameters for SAR image formation from the ephemeris data. In the FPGA processor, range compression focuses the image in the cross track direction. The presum module resamples the pulses to a user-specified along track location and spacing to reduce the number of pulses to process in the along track (azimuth) direction while reducing the noise on each radar pulse. Motion compensation is the process where the radar signal data are resampled from the actual path of the antenna to an idealized path called the reference path. This process is necessary to align the phase centers of two data channels to the same reference path to ensure maximum correlation. Azimuth processing focuses the image in the along track direction. Radiometric and phase calibrations are necessary to generate polarimetric or interferometric science data products.

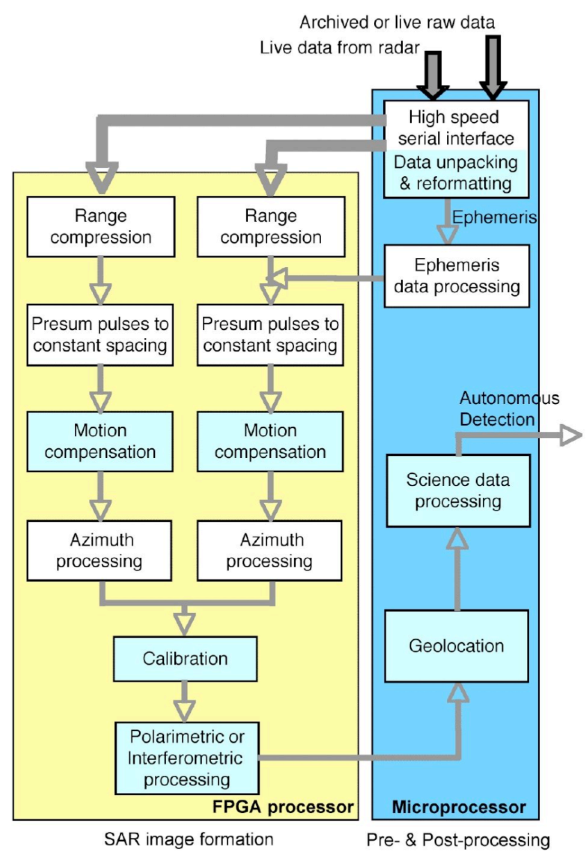

Figure 4. UAVSAR onboard processor flow.

The post-processor geolocates the two SAR images with information from the ephemeris data and generates application-specific science data products such as the biomass and fuel load map. The science data products are routed via Ethernet to a laptop or UAVSAR's ROW for disturbance detection and monitoring.

V. AUTOMATED ONBOARD RESPONSE

Autonomous disturbance detection and response to natural phenomena such as volcanic eruption and glacier movement have recently been demonstrated by ASE with a hyperspectral sensor onboard the New Millenium EO-1 spacecraft [5]. The onboard automated response component, which includes the CASPER software, enables the overall system to modify its future mission plan based on an onboard analysis of data.

In this effort we are adapting the CASPER mission planning engine to demonstrate retargeting of assets based on rapid processing of science to retask the SAR platform based on analysis of its prior acquisition. In this scenario, the SAR platform is demonstrating closed loop autonomy similar to that demonstrated on the Autonomous Sciencecraft on the EO-1 Mission. We are demonstrating the ability of the SAR platform to 1) observe a target; 2) process the science data from that target to detect a science event (e.g., lake thaw, flooding event); 3) replan the UAVSAR operations to accommodate a high priority re-observation; and 4) execute this observation.

One particular challenge with onboard mission planning for a UAVSAR is the spatial reasoning required to correctly understand mission objectives. While the flight control system provides a high level tracking and understanding at the level of waypoints, this high level spatial information (including regarding the science targets – fire, storms, etc.) must be integrated with the states and resources of the air vehicle. In this effort, we will adapt prior work in spatial reasoning about airspace [6] as well as prior work in integrating specialized spatial solvers (such as path planners) from prior spacecraft and rover autonomy work [7,8]. The spatial block representations [6] provide an efficient basis for mission planning to represent spatial features, identify obstacles, and interpret waypoints.

VI. DEVELOPMENT PLAN

The UAVSAR-based automated disturbance detection and monitoring system is a three-year development effort. We are in year 1 of the effort and we are focusing on developing the high level architecture of the smart sensor, the high rate data interfaces (raw radar data and ephemeris), the flight planning interface, and on selecting appropriate science algorithms for forest fire and hurricane damage applications. We have also begun to adapt the onboard SAR processor algorithm for UAVSAR.

In year 2, we will complete the onboard SAR image formation capability and begin to address the calibration requirements. We will also complete the onboard replanning interface with the UAVSAR. We will begin developing the science data processing and disturbance detection capabilities. By the end of year 2, we plan to demonstrate real-time SAR image formation with UAVSAR data and onboard replanning capability. In year 3, we will focus on packaging the entire smart sensor with autonomous decision making for forest fire and hurricane damage applications and demonstrate closed loop autonomy with UAVSAR. We will also actively seek collaboration with other sensor webs such as the forest fire sensor web with EO-1 to demonstrate smart sensor operation as an element of a sensor web.

ACKNOWLEDGMENT

The work carried out in this paper was performed at Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration (NASA). The authors wish to thank NASA's Earth Science Technology Office for funding this technology development through the Advanced Information System Technology program.

REFERENCES

[1] Lou, Y., S. Hensley, C. Le, and D. Moller, "Onboard processor for direct distribution of change detection data products," Proceedings of the IEEE Radar Conference, pp. 33-37, 2004.

[2] Finney, M.A., "FARSITE: Fire area simulator – model development and evaluation," Research Paper RMRS-RP-4, Ogden, UT: USDA Forest Service Rocky Mountain Research Station, 1998.

[3] Anderson, H.-E., et al., "Estimating canopy fuel parameters in a Pacific Northwest conifer forest using multi-temporal polarimetric IFSAR," Proceeding of ISPRS Commission III, WG III/3, Istanbul, Turkey, 2004.

[4] Saatchi, S., D. Despain, K. Halligan, and R. Crabtree, "Estimating forest fuel load from radar remote sensing," IEEE Trans. on Geosceince and Remote Sensing, in press.

[5] Chien, S., R. Sherwood, D. Tran, B. Cichy, G. Rabideau, R. Castano, A. Davies, D. Mandl, S. Frye, B. Trout, S. Shulman, D. Boyer, "Using Autonomy Flight Software to Improve Science Return on Earth Observing One," Journal of Aerospace Computing, Information, and Communication, April 2005.

[6] Knight, R., "Lightweight Simulation of Air Traffic Control Using Simple Temporal Networks," Workshop on Spatial and Temporal Reasoning, International Joint Conference on Artificial Intelligence (IJCAI 05), Edinburgh, Scotland, 2005.

[7] Knight, R., B. Smith, R. Korf, and S. Chien, "Integrating Combinatorial Solvers with Automated Mission Planning," Final Report, NASA Intelligent Systems Program, 2005.

[8] Estlin, T., D. Gaines, F. Fisher, R. Castano, "Coordinating Multiple Rovers with Interdependent Science Objectives," Autonomous Agents and Multi-Agent Systems Conference (AAMAS 2005), Utrecht, Netherlands, 2005